The LIGO Science Education Center's Exterior Kinetic Pendulum Wall Exhibit

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The LIGO Science Education Center (SEC) design posed difficult challenges for architects Steve Dumez and Kevin Morris (Eskew+Dumez+Ripple Architects, New Orleans). Our occupancy and exhibit space requirements demanded an area and volume barely consistent with the available budget. At the same time, our ultimate function—to invite and engage students and the public in LIGO science—would be served poorly by the most cost-effective construction available, a straight-sided industrial metal warehouse.

Taking inspiration from other large-scale art and public outreach projects, including some from their own portfolio, E+D+R proposed to incorporate a science-themed educational exhibit as the exterior "skin" of an otherwise conventional low-cost structure. This approach turns the architectural disadvantage of expansive, inert, planar walls into an opportunity: vast, *highly visible and accessible* display space.

LIGO and our SEC partners at the San Francisco Exploratorium began intensive brainstorming with E+D+R. We explored numerous concepts, drawing on our focal LIGO-science themes: waves, resonance, light, gravity, and the use of scientific instruments to perceive the invisible. Candidate approaches included giant-scale astrophysical graphics, holographic displays, and wavelike Moiré patterns formed of layered perforated metal.

We agreed that the most engaging and inspirational kind of display would involve both novelty of perception and physical motion. We looked, for example, at the visitor-activated motion/sound sculptures by Paul Matisse in the Kendall "T" station in Cambridge, MA. We were also were drawn to the shimmering wind-driven architectural sculptures of artist Ned Kahn (see http://nedkahn.com/). Unfortunately this approach was about a factor of three too expensive at the intended SEC scale (over 2,500 square feet are required).

However the quest inspired physicist Thomas Humphrey and artists Peter Richards, Shawn Lani, Susan Schwartzenberg and Charles Sowers (all with the Exploratorium) to develop an even bolder approach on a much lower budget: a magnetically coupled wave machine more than thirty feet high, suspended above the 85 foot approach to the building (Figure 1).

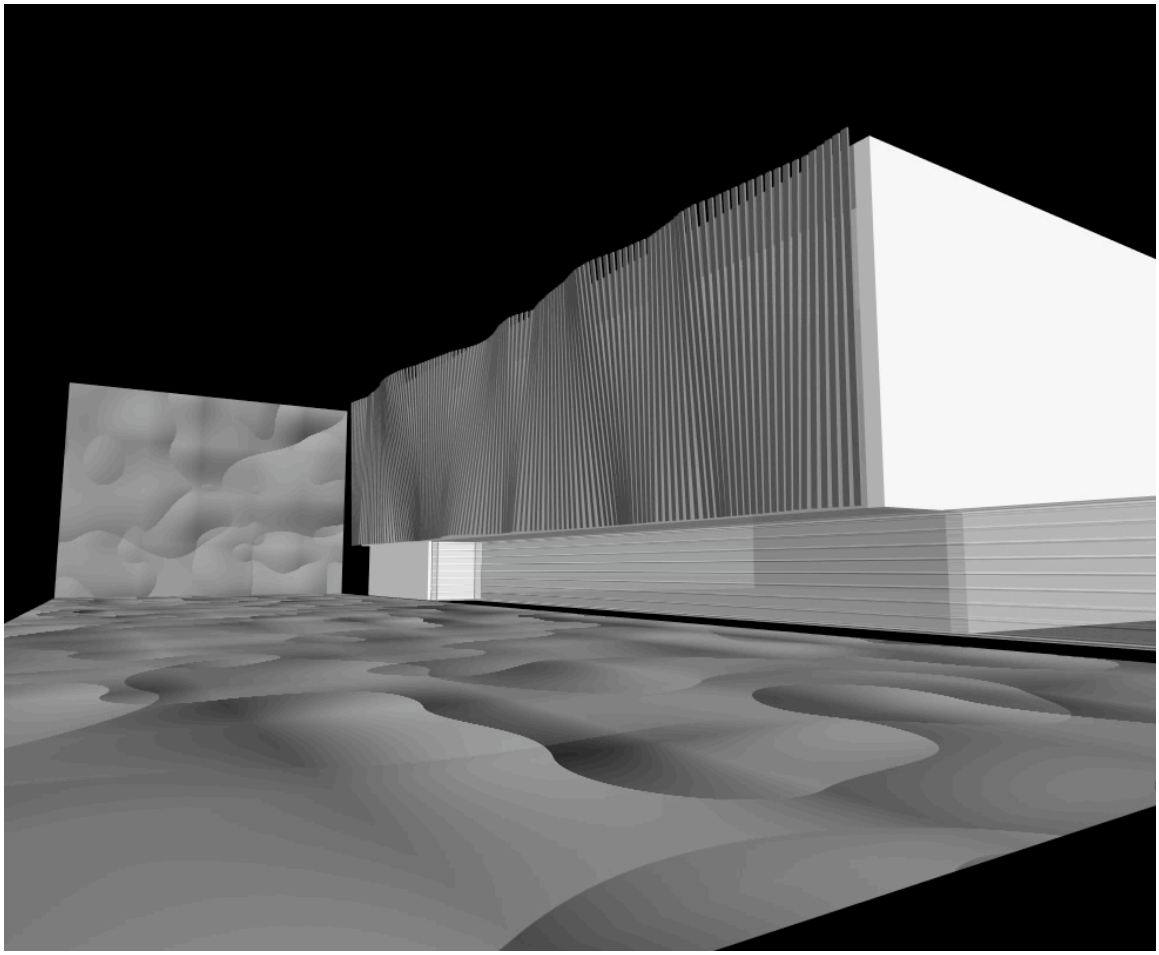

Figure 1: Concept sketch of LIGO SEC with kinematic coupled pendulum façade covering South wall and entry walk (K. Morris, E+D+R).

Approximately 130 aluminum alloy masts (each a 2" x 6" rectangular tube, 27 feet long) are suspended on low-friction bearings near their centers of gravity, to form nearly independent pendula with natural periods of about ten seconds. A permanent magnet attached to each mast couples it weakly to its neighbors. In this way wind-driven (and visitor-induced) disturbances will be transmitted from mast to mast, forming torsional waves at a ponderous and impressive speed. The visual impact of this display seen from a distance will be underscored by intimate experience, as visitors enter the SEC by walking under and inside the exhibit for its full length. The lower extremity of each mast will swing 8 feet above the walkway, just overhead.

Figure 2: Test of a short section of magnetically coupled kinetic pendulum façade at the Exploratorium in March 2005. (M. Zucker, LLO)

We will provide means for students and guests to drive the pendula, lock selected elements, and perform wave experiments like those we perform on our smaller scale exhibits (e.g., the "Wave Machine[1]" and "Giant Slinky," already in service at LIGO). One of the simplest and most engaging such experiments involves deliberately limiting the force a visitor can apply, so that a persistent effort to maintain a consistent excitation phase is rewarded by a surprising amplitude. The added challenge seems to add focus and invite deeper inquiry; the Exploratorium's "Resonant Pendulum[2]" illustrates this

[1] http://www.exploratorium.edu/cmp/exhibits/w/wave_machine.html

[2] http://www.exploratorium.edu/cmp/exnet/exhibits/group2/resonant_pend/media/resonant_s.pdf

principle nicely, and it also forms a central feature of the Matisse installations mentioned above.

Irrespective of visitor presence, we still can count on a continuum of rich and interesting behavior any time there is wind. The elements are designed to project above the facility roofline, affording an aerodynamic cross section from all directions. A prototype test in March at the Exploratorium's engineering site bore this prediction out (see Figure 2; a brief video of this test is also available for viewing online[3]). Of course, for our LLO installation the mast amplitude will be passively limited by bumpers (to about two meters) and a locking provision will secure the elements during storm conditions.

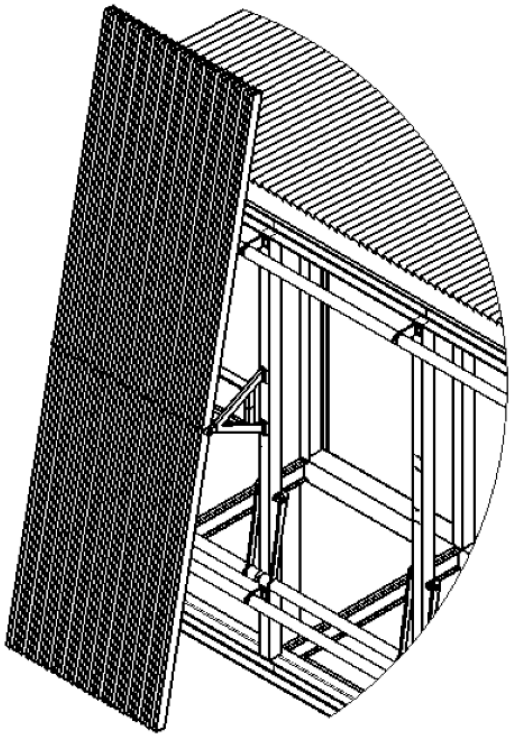

Figure 3: Excerpt from engineering drawings of kinematic pendulum façade structural support, showing limit bumpers, axle truss and locking mechanism. (O. Spjeld, LLO)

A joint design group comprising E+D+R, Exploratorium and LIGO Livingston engineers is pursuing the design of the exhibit. The building steelwork has been analyzed and

[3] http://www.exo.net/dropbox/Ligo_Wall_High_Quality.mov

designed to sustain its loads and provide attachments. LIGO and E+D+R will manage design, fabrication and integration using a separate bid contract distinct from conventional construction. This permits building at the most aggressive possible speed while exhibit features are being further defined, value-engineered and tested.

Several added features already included unlock further potential for learning and inspiration. The spacing and shape of the vertical elements has been chosen to afford a variable Moiré- like optical pattern enhancement from a range of viewing angles. The motion will also modulate shafts of sunlight projected into the SEC entrance hall through full-height translucent wall panels. Each element will also be anodized with a bright finish to throw moving shafts of sunlight onto the lawn and the existing exterior pavilion (some of this behavior can be seen in the video clip linked above). We feel the installation thus has the potential not only to engage visitors' curiosity, but also to invite inquiry on virtually every LIGO science education theme; revealing the invisible, wave motion and propagation, resonance, gravity, and light.

Figure 4: A (static) architectural frontispiece at the Athens Olympics sports complex, suggesting the scale and visual impact of the planned SEC façade. (Santiago Calatrova, 2004)

We also expect the kinematic façade to reach well beyond the limits of our Louisiana site. The LIGO SEC is being equipped to reach virtual visitors through the SEC's web portal (a project spearheaded by our collaborators at Southern University of Baton Rouge). A set of video webcam perspectives will allow remote monitoring of the exhibit's undulations and light patterns. Video will also give a simultaneous view of the interaction areas (where visitors may be exciting the structure). In addition, a live feed of current wind conditions from the LIGO weather station will be provided. In this way remote viewers can participate in discovering the connection between artificial and natural excitations, resonant patterns, and motion. The possibility has also been proposed to develop a remote-controlled excitation mechanism, such that "virtual" visitors may even excite the exhibit themselves while observing the results.

The Exploratorium has expressed interest in featuring this exhibit, possibly via web kiosk, to augment its offerings of related exhibits in San Francisco. Some of these include Frank Oppenheimer's original "Coupled Pendulums[4]" as well as the more recent "Magnetic Wave Machine[5]" (Figure 5) and the mesmerizing "Pendulum Snake[6]." The latter two exhibits are already part of the SEC's exhibit collection and are currently used at LIGO for outreach and teacher professional development.

[4] http://www.exploratorium.edu/cmp/exhibits/c/coupled_pend.html
[5] http://www.exploratorium.edu/cmp/exnet/exhibits/group8/mag_wave_machine/
[6] http://www.exploratorium.edu/cmp/exnet/exhibits/group6/pend_snake/

Figure 5: Indoor-scale "Magnetic Wave Machine" at the San Francisco Exploratorium (Exploratorium photo)

We anticipate other science and technology centers may also choose to share in displaying and exploring the SEC exhibit remotely at their home locations. These links will be promoted by LIGO SEC's active membership in the Association of Science-Technology Centers (ASTC), the American Physical Society, the American Association of Physics Teachers, and other national organizations. LIGO outreach and science staff participate in workshops and present papers at annual meetings, affording opportunities for broad national exposure.

Both direct interaction on site and remote web access to images of the installation will lend motivation and learning power to classroom-scale activities based on the same principles. Inspired by the Exploratorium's "Snack" and "Cookbook" series, these activities will let kids anywhere replicate similar dynamics through activities performed in their own classrooms, with readily available materials. Related examples are highlighted at the Exploratorium's web site[7,8] along with teaching guides and support

[7]http://www.exploratorium.edu/snacks/magnetic_pendulums.html

materials. LIGO will develop comparable activities based on the pendulum wall to include in our site-based PD and direct student programs (for classroom follow-up), and will offer these worldwide over our web portal.

The prominence of the pendulum wall will establish a kind of visual "signature" for the SEC (and in turn for LIGO itself). Featured graphically on our printed and web materials, and greeting site visitors as our "frontispiece," the kinetic pendulum wall will draw the eye and engage curiosity; at the same time, its rich physics content will provide a powerful hook to LIGO science themes.

[8] http://www.exploratorium.edu/snacks/coupledrespend/index.html